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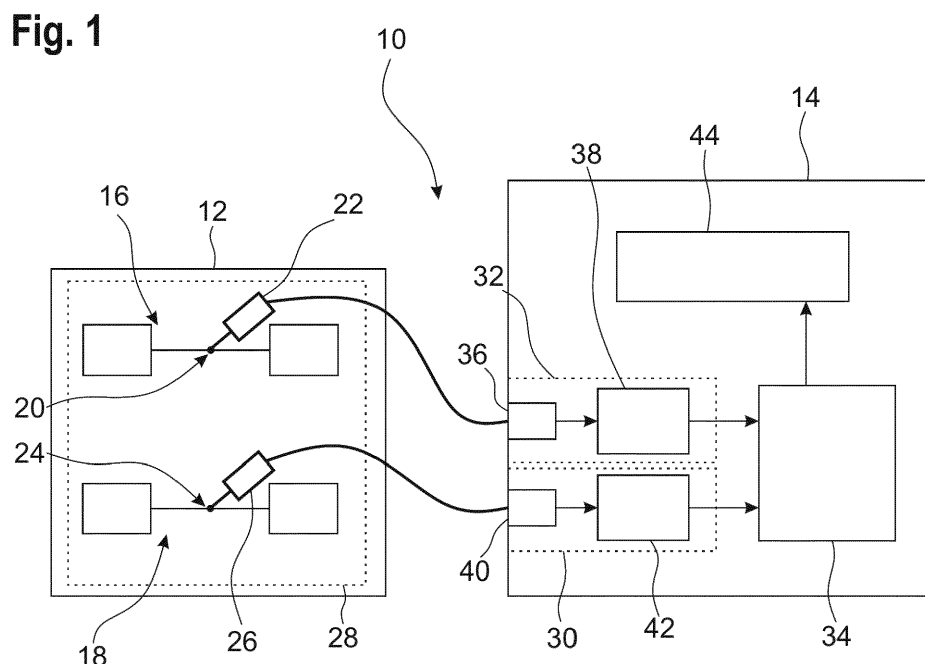
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MEASUREMENT INSTRUMENT, MEASUREMENT SYSTEM, AND SIGNAL PROCESSING METHOD

(57)

A measurement instrument (14) for testing a device under test is described. The device under test (12) has at least two test points (20, 24). The measurement instrument (14) comprises a first measurement channel (30), a second measurement channel (32), and a machine-learning module (34). The first measurement channel (30) is configured to process a first input signal associated with one of the at least two test points (20, 24), thereby generating a first measurement signal. The second measurement channel (32) is configured to process

a second input signal associated with another one of the at least two test points, thereby generating a second measurement signal. The machine-learning module (34) is configured to determine at least one correlation quantity based on the first measurement signal and based on the second measurement signal, wherein the at least one correlation quantity is indicative of a correlation between the first measurement signal and the second measurement signal. Further, a measurement system (10) and a signal processing method are described.



Description

[0001] The invention generally relates to a measurement instrument for testing a device under test. The invention further relates to a signal processing method for testing a device under test.

[0002] In some cases, a particular signal of an electronic system may be failing to fulfill its requirements some or all of the time. There can be several reasons for this failure, e.g. an inappropriate board design or suboptimal settings concerning the signal itself.

[0003] Another reason for such a failure can be influences from other signals within the electronic system. In this case, the user of the electronic system has to determine which signal is causing the problems in the signal under observation. The terminology 'find the aggressor' is often used to describe this type of debugging problem.

[0004] Typically, sets of signals are observed for long periods of time in order to observe any relationships between the signal under observation and any potential aggressor signals. If the relationships are not obvious, e.g. some kind of linear coupling, finding the aggressor can be a time consuming task.

[0005] Thus, the object of the present invention is to provide a measurement instrument, a measurement system, and a signal processing method that allow for an easier identification of aggressor signals.

[0006] According to the invention, a measurement instrument is provided that is used for testing a device under test that has at least two test points. The measurement instrument comprises a first measurement channel, a second measurement channel, and a machine-learning module. The first measurement channel is configured to process a first input signal associated with one of the at least two test points, thereby generating a first measurement signal. The second measurement channel is configured to process a second input signal associated with another one of the at least two test points, thereby generating a second measurement signal. The machine-learning module is configured to determine at least one correlation quantity based on the first measurement signal and based on the second measurement signal, wherein the at least one correlation quantity is indicative of a correlation between the first measurement signal and the second measurement signal.

[0007] The invention is based on the idea to analyze correlations between the first measurement signal and the second measurement signal by means of the machine-learning module using a suitable machine-learning technique.

[0008] More precisely, the machine-learning module is trained to determine the at least one correlation quantity based on the first management signal and based on the second measurement signal in a fully automatic manner.

[0009] If there is a certain amount of correlation between the measurement signals, this is a strong indicator that an electronic component of the device under test

generating the first input signal may be influencing an electronic component of the device under test generating the second input signal or vice versa.

[0010] Accordingly, the at least one determined correlation quantity can be used for identifying aggressor signals within the device under test.

[0011] Particularly, the machine-learning module may be configured to automatically determine if at least one of the first input signal and the second input signal is an aggressor signal (i.e. unwantedly influences the other input signal) based on the at least one correlation quantity determined.

[0012] Alternatively or additionally, the at least one correlation quantity may be displayed to a user, such that the user of the measurement instrument may decide whether one of the input signals is an aggressor signal based on the at least one correlation quantity determined.

[0013] Even if the final conclusion about the aggressor signal is not performed by the machine-learning module, the at least one determined correlation quantity is easier to handle for the user than a bulk of data comprising a long-term observation of the first input signal and of the second input signal. Accordingly, the measurement instrument according to the invention is easier to handle for a user.

[0014] Moreover, the at least one correlation quantity is determined fully automatic, such that the needed time for identifying aggressor signals is significantly reduced.

[0015] According to an aspect of the present invention, the machine-learning module comprises an artificial neural network. The artificial neural network is trained to determine the at least one correlation quantity based on the first measurement signal and based on the second management signal. The first measurement signal and/or the second measurement signal are input quantities of the artificial neural network. The at least one correlation quantity is an output quantity of the artificial neural network.

[0016] According to a further aspect of the present invention, the artificial neural network comprises an autoencoder. The first measurement signal and/or the second measurement signal are input quantities of the autoencoder. The at least one correlation quantity is an output quantity of the autoencoder.

[0017] The autoencoder may be trained to extract the most relevant information from the first measurement signal and/or from the second measurement signal, and to determine the at least one correlation quantity based on the information extracted.

[0018] In an embodiment of the present invention, the machine-learning module is configured to try to reconstruct the second measurement signal based on the first measurement signal in order to determine the at least one correlation quantity. In other words, the machine-learning module is trained to reconstruct the second measurement signal based on the first measurement signal (or vice versa). If the machine-learning module succeeds in reconstructing the second measurement signal

(at least partially) based on the first measurement signal, this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0019] According to another aspect of the present invention, the at least one correlation quantity comprises a reconstruction function, wherein the reconstruction function describes a dependency of the second measurement signal on the first measurement signal. In other words, the machine-learning module tries to find a reconstruction function $S_2(x) = f(S_1(x))$ that describes the second measurement signal $S_2(x)$ in dependence of the first measurement signal $S_1(x)$, wherein x represents a time variable and/or a frequency variable. If such a function f can be found, this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0020] The reconstruction function f may be a non-linear function. Accordingly, non-linear correlations between the input signals can be identified. Thus, using a machine-learning module in order to determine the at least one correlation quantity has the additional advantage that non-linear correlations can be identified.

[0021] Particularly, the machine-learning module may be trained to find a (non-linear) reconstruction function $S_2(x) = f(S_{1,i}(x), S_{2,i}(x))$ that describes the second measurement signal $S_2(x)$ in dependence of an ideal first measurement signal $S_{1,i}(x)$ and in dependence of an ideal second measurement signal $S_{2,i}(x)$, i.e. based on measurement signals without any perturbation due to aggressor signals. If such a reconstruction function f can be found (and the dependence on $S_{2,i}(x)$ is non-trivial) this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0022] The ideal measurement signals $S_{1,i}(x)$ may be obtained by measuring the first input signal while the electronic component of the device under test generating the second input signal is turned off. Likewise, the ideal measurement signal $S_{2,i}(x)$ may be obtained by measuring the second input signal while the electronic component of the device under test generating the first input signal is turned off.

[0023] In a further embodiment of the present invention, the first measurement channel is configured to pre-process the first input signal such that the first measurement signal comprises statistical information regarding the first input signal.

[0024] Alternatively or additionally, the second measurement channel may be configured to pre-process the second input signal such that the second measurement signal comprises statistical information regarding the

second input signal.

[0025] The statistical information may, for example, comprise a pulse-width-histogram of any one of the input signals, a signal-to-noise ratio of any of the input signals, an/or an average power of any of the input signals.

[0026] Accordingly, additional information on the first input signal and/or the second input signal is provided, which can be used by the machine-learning module in order to determine the at least one correlation quantity.

[0027] Particularly, the machine-learning module is configured to determine the at least one correlation quantity based on the statistical information. This way, the accuracy of the at least one correlation parameter determined may be enhanced.

[0028] According to an aspect of the present invention, the measurement instrument is configured to process at least one further input signal, thereby generating at least one further measurement signal, wherein the machine-learning module is configured to determine the at least one correlation quantity based on the at least one further measurement signal, and wherein the at least one correlation quantity is indicative of a correlation between the at least one further measurement signal and at least one of the first measurement signal and the second measurement signal. Accordingly, the machine-learning module may be trained to determine whether there is a significant correlation between two or more of first input signal, the second input signal, and the at least one further input signal.

[0029] Particularly, the machine-learning module may be configured to determine the at least one correlation quantity for all possible pairs of measurement signals, such that a separate correlation quantity is obtained for all possible pairs of input signals. Thus, the influence of each input signal on all other input signals is checked.

[0030] Alternatively or additionally, the machine-learning module may be configured to determine the at least one correlation quantity for groups of measurement signals, such that the at least one correlation quantity is indicative of a correlation between different groups of input signals.

[0031] The at least one further input signal may be processed by means of the first measurement channel, by means of the second measurement channel, and/or by means of a further measurement channel of the measurement instrument.

[0032] In a further embodiment of the present disclosure, the machine-learning module is configured to transform the first measurement signal and/or the second measurement signal to a latent space in order to determine the at least one correlation quantity. In other words, the machine-learning module may be configured to extract the most relevant information from the first measurement signal and/or from the second measurement signal, and to determine the at least one correlation quantity based on the information extracted. It has turned out that perturbations in any of the input signals that only occur sporadically can be identified based on a latent space

representation of the measurement signals. In other words, the machine-learning module can identify aggressor signals even if the perturbations caused by the aggressor signal only occur sporadically.

[0033] Moreover, it has turned out that outlier samples in the measurement signals can be identified and treated appropriately based on the latent space representation of the measurement signals.

[0034] Particularly, the measurement instrument is established as an oscilloscope, as a signal analyzer, or as a vector network analyzer. However, it is to be understood that the measurement instrument may be established as any other type of suitable signal analysis instrument.

[0035] According to the invention, the problem further is solved by a measurement system. The measurement system comprises a device under test and a measurement instrument described above, wherein the device under test has at least two test points.

[0036] Regarding the advantages and further properties of the measurement system, reference is made to the explanations given above with respect to the measurement instrument, which also hold for the measurement system and vice versa.

[0037] According to an aspect of the present invention, the device under test comprises a printed circuit board, wherein the printed circuit board comprises the at least two test points. Thus, the measurement instrument described above can be used for testing printed circuit boards with respect to aggressor signals. In other words, the measurement instrument can be used to identify electronic components, e.g. electronic circuits, influencing other electronic components, e.g. electronic circuits, printed on the printed circuit board.

[0038] According to the invention, the problem further is solved by a signal processing method for testing a device under test. The device under test has at least two test points. The signal processing method comprises the following steps:

- receiving a first input signal via a first measurement channel and a second input signal via a second measurement channel;
- processing the first input signal by means of the first measurement channel, thereby generating a first measurement signal;
- processing the second input signal by means of the second measurement channel, thereby generating a second measurement signal; and
- determining at least one correlation quantity being indicative of a correlation between the first measurement signal and the second measurement signal by means of a machine-learning technique.

[0039] Particularly, the measurement instrument de-

scribed above and/or the measurement system described above are/is configured to perform the signal processing method.

[0040] Regarding the advantages and further properties of the signal processing method, reference is made to the explanations given above with respect to the measurement instrument, which also hold for the signal processing method and vice versa.

[0041] According to an aspect of the present invention, the signal processing method further comprises the following step:

- trying to reconstruct the second measurement signal based on the first measurement signal by means of the machine-learning technique in order to determine the at least one correlation quantity.

[0042] If the machine-learning module succeeds in reconstructing the second measurement signal (at least partially) based on the first measurement signal, this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0043] According to another aspect of the present invention, the at least one correlation quantity comprises a reconstruction function, wherein the reconstruction function describes a dependency of the second measurement signal on the first measurement signal. In other words, the machine-learning module tries to find a reconstruction function $s_2(x) = f(s_1(x))$ that describes the second measurement signal $s_2(x)$ in dependence of the first measurement signal $s_1(x)$, wherein x represents a time variable and/or a frequency variable. If such a function f can be found, this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0044] The reconstruction function f may be a non-linear function. Accordingly, non-linear correlations between the input signals can be identified.

[0045] Particularly, the machine-learning module may try to find a (non-linear) reconstruction function $S_2(x) = f(S_{1,i}(x), S_{2,i}(x))$ that describes the second measurement signal $S_2(x)$ in dependence of an ideal first measurement signal $S_{1,i}(x)$ and in dependence of an ideal second measurement signal $S_{2,i}(x)$, i.e. based on measurement signals without any perturbation due to aggressor signals. If such a reconstruction function f can be found (and the dependence on $S_{2,i}(x)$ is non-trivial) this is a strong indicator for a correlation between the measurement signals, and thus between the input signals. Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0046] The ideal measurement signals $S_{1,i}(x)$ may be

obtained by measuring the first input signal while the electronic component of the device under test generating the second input signal is turned off. Likewise, the ideal measurement signal $S_{2,i}(x)$ may be obtained by measuring the second input signal while the electronic component of the device under test generating the first input signal is turned off.

[0047] The foregoing aspects and many of the attendant advantages of the claimed subject matter will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

- Figure 1 schematically shows a measurement system according to the present invention;
- Figure 2 shows an ideal device under test with the associated measurement signals;
- Figure 3 shows a device under test having an aggressor signal and the associated measurement signals;
- Figure 4 shows a flow chart of a signal processing method according to the present invention; and
- Figures 5 and 6 show illustrations of individual steps of the signal processing method of Figure 4.

[0048] The detailed description set forth below in connection with the appended drawings, where like numerals reference like elements, is intended as a description of various embodiments of the disclosed subject matter and is not intended to represent the only embodiments. Each embodiment described in this disclosure is provided merely as an example or illustration and should not be construed as preferred or advantageous over other embodiments. The illustrative examples provided herein are not intended to be exhaustive or to limit the claimed subject matter to the precise forms disclosed.

[0049] For the purposes of the present disclosure, the phrase "at least one of A, B, and C", for example, means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B, and C), including all further possible permutations when more than three elements are listed. In other words, the term "at least one of A and B" generally means "A and/or B", namely "A" alone, "B" alone or "A and B".

[0050] Figure 1 schematically shows a measurement system 10 comprising a device under test 12 and a measurement instrument 14.

[0051] The device under test 12 comprises at least two different electronic circuits that are each configured to generate and/or process electric signals.

[0052] In the particular example shown in Figure 1, the device under test comprises a first electronic circuit 16 configured to generate and/or process a first electric signal $s_1(t)$, and a second electronic circuit 18 configured to

generate and/or process a second electric signal $s_2(t)$.

[0053] The first electronic circuit 16 comprises a first test point 20 via which the first electric signal $s_1(t)$ can be picked up, e.g. by means of a first measurement probe 22 connected to the measurement instrument 14.

[0054] The second electronic circuit 18 comprises a second test point 24 via which the second electric signal $s_2(t)$ can be picked up, e.g. by means of a second measurement probe 26 connected to the measurement instrument 14.

[0055] In general, the device under test 12 may be established as any kind of electronic device.

[0056] Optionally, the device under test 12 may comprise a printed circuit board 28, wherein the electronic circuits 16, 18 are printed on the printed circuit board 28.

[0057] In fact, the device under test 12 may even be established as a printed circuit board.

[0058] In general, the measurement instrument 14 may be established as an oscilloscope, as a signal analyzer, or as a vector network analyzer.

[0059] However, it is to be understood that the measurement instrument 14 may be established as any other type of suitable signal analysis instrument.

[0060] The measurement instrument 14 comprises a first measurement channel 30, a second measurement channel 32, and a machine-learning module 34.

[0061] Therein and in the following, the term "module" is understood to describe suitable hardware, suitable software, or a combination of hardware and software that is configured to have a certain functionality.

[0062] The hardware may, inter alia, comprise a CPU, a GPU, an FPGA, an ASIC, or other types of electronic circuitry.

[0063] The first measurement channel 30 comprises a first signal input 36 being connected to the first measurement probe 22.

[0064] The first measurement channel 30 further comprises a first signal processing module 38 being interconnected between the first signal input 36 and the machine-learning module 34.

[0065] The second measurement channel 32 comprises a second signal input 40 being connected to the second measurement probe 26.

[0066] The second measurement channel 32 further comprises a second signal processing module 42 being interconnected between the second signal input 40 and the machine-learning module 34.

[0067] Electronic devices having several signal processing and/or signal generating circuits may bear the problem that the individual electronic circuits influence each other in an unwanted fashion, thereby causing perturbations in one or several of the electronic signals.

[0068] In the particular example of Figure 1, the first electric signal $s_1(t)$ may influence the second electric signal $s_2(t)$ in an unwanted manner or vice versa.

[0069] Figure 2 shows an exemplary device under test 12 having four different electronic circuits generating/processing four electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and

$s_4(t)$.

[0070] In fact, the device under test 12 shown in Figure 2 is an ideal electronic device, in the sense that there are no aggressor signals. In other words, the four electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and $s_4(t)$ do not influence each other in an unwanted manner.

[0071] Accordingly, the four electric signals are ideal electric signals $s_{1,i}(t)$, $s_{2,i}(t)$, $s_{3,i}(t)$, and $s_{4,i}(t)$.

[0072] Figure 3 shows the same device under test 12, but with a perturbation in the third electric signal $s_3(t)$ due to an unwanted perturbation from any of the other electric signals $s_1(t)$, $s_2(t)$, and $s_4(t)$.

[0073] The measurement instrument 14 can be used to identify the aggressor signal(s) in the device under test 12.

[0074] More precisely, the measurement instrument 14 is configured to perform a signal processing method for testing the device under test 12 that is described in the following with reference to Figure 4.

[0075] In the following, the signal processing method is described for the particular example of the device under test 12 shown in Figure 3. However, it is to be understood that the signal processing method is also applicable to any other number of electric signals bigger than or equal to 2.

[0076] A first input signal and a second input signal received via the first measurement channel 30 and the second measurement channel 32, respectively (step S1).

[0077] Therein, the first input signal may be any one of the electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and $s_4(t)$.

[0078] The second input signal may be any other one of the electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and $s_4(t)$.

[0079] The first input signal and the second input signal are processed by means of the first signal processing module 38 and the second signal processing module 42, respectively, thereby generating a first measurement signal and a second measurement signal, respectively (step S2).

[0080] The input signals are received and processed over a predetermined period of time, such that measurement data of the input signals (i.e. the measurement signals) is available over the predetermined period of time.

[0081] More precisely, multiple recordings of each input signal may be generated.

[0082] Steps S1 and S2 may be repeated until measurement signals are generated for each of the electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and $s_4(t)$ of the device under test 12.

[0083] This is illustrated in Figure 5, which shows four sets of measurement signal data associated with the measurement signals S_1 , S_2 , S_3 , and S_4 that are observed over a predetermined time T.

[0084] Alternatively or additionally, the measurement instrument 14 may comprise additional measurement channels, such that more input signals can be received and processed at the same time.

[0085] Optionally, the first input signal and the second input signal may be preprocessed by means of the first

signal processing module 38 and the second signal processing module 42, respectively, such that the first measurement signal and the second measurement signal comprise statistical information regarding the first input signal and the second input signal, respectively (step S3).

[0086] The statistical information may, for example, comprise a pulse-width-histogram of any one of the input signals, a signal-to-noise ratio of any of the input signals, and/or an average power of any of the input signals.

[0087] The measurement signals are forwarded to the machine-learning module 34.

[0088] At least one correlation quantity is determined by means of the machine-learning module 34, wherein the at least one correlation quantity is indicative of a correlation between at least one pair of measurement signals being associated with the electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, and $s_4(t)$ (step S4).

[0089] In general, the machine-learning module 34 is trained to determine the at least one correlation quantity based on the respective measurement signals, i.e. based on samples associated with the electric signals $s_1(t)$, $s_2(t)$, $s_3(t)$, $s_4(t)$ and, optionally, based on the additional statistical information.

[0090] More precisely, the machine-learning module 34 comprises an artificial neural network, particularly and autoencoder, that is trained to determine the at least one correlation quantity based on the respective measurement signals.

[0091] The at least one correlation quantity may comprise a correlation coefficient C between at least one pair of measurement signals, particularly for each pair of measurement signals.

[0092] For example, the correlation coefficient C may be a Pearson correlation coefficient.

[0093] Accordingly, the at least one correlation quantity may comprise correlation coefficients $C(S_1(t), S_2(t))$, $C(S_1(t), S_3(t))$, $C(S_1(t), S_4(t))$, $C(S_2(t), S_3(t))$, $C(S_2(t), S_4(t))$, and/or $C(S_3(t), S_4(t))$.

[0094] Therein and in the following, signals with capital letters S_1 , S_2 , etc. denote the measurement signal associated with the respective electric signal with lower-case letters, i.e. s_1 , s_2 , etc.

[0095] However, such correlation coefficients C only capture linear correlations between the respective signals.

[0096] Preferably, the at least one correlation quantity comprises at least one reconstruction function f , wherein the reconstruction function describes a dependency of one or several measurement signal on one or several other measurement signals.

[0097] In other words, the machine-learning module 34 tries to reconstruct at least one of the measurement signals S_1 , S_2 , S_3 , S_4 based on at least one other of the measurement signals S_1 , S_2 , S_3 , S_4 .

[0098] This is illustrated in Figure 6, wherein an autoencoder of the machine-learning module 34 tries to reconstruct the measurement signal S_4 based on the

measurement signal S_3 .

[0099] Accordingly, in this example, the measurement signal S_3 is an input quantity of the autoencoder, while the measurement signal S_4 is a target output quantity of the autoencoder.

[0100] For example, the machine-learning module 34 may be trained to find a (non-linear) reconstruction function $S_2(x) = f(S_{1,i}(x), S_{2,i}(x))$ that describes the second measurement signal $S_2(x)$ in dependence of an ideal first measurement signal $S_{1,i}(x)$ and in dependence of an ideal second measurement signal $S_{2,i}(x)$, i.e. based on measurement signals without any perturbation due to aggressor signals.

[0101] Therein, x represents a time variable and/or a frequency variable. Accordingly, the measurement signals may be transformed to frequency domain before trying to find the reconstruction function(s) f .

[0102] If such a function f can be found, this is a strong indicator for a correlation between the respective measurement signals, and thus between input signals associated with the measurement signals.

[0103] Accordingly, in this case it can be concluded that the first input signal is an aggressor signal with respect to the second input signal.

[0104] The reconstruction function f may be a non-linear function. Accordingly, non-linear correlations between measurement signals (and thus between the input signals) can be identified.

[0105] The ideal measurement signals $S_{1,i}(x)$ may be obtained by measuring the first input signal (or rather the first electric signal $s_1(t)$) while the electronic component of the device under test 12 generating the second input signal (or rather the second electric signal $s_2(t)$) is turned off.

[0106] Likewise, the ideal measurement signal $S_{2,i}(x)$ may be obtained by measuring the second input signal (or rather the second electric signal $s_2(t)$) while the electronic component of the device under test 12 generating the first input signal (or rather the first electric signal $s_1(t)$) is turned off.

[0107] Particularly, the machine-learning module 34 may try to determine a respective reconstruction function f for all possible pairs of measurement signals, such that a separate reconstruction function f is obtained for all possible pairs of measurement signals. This way, the influence of each input signal on all other input signals is checked.

[0108] It is noted that the reconstruction functions f for different pairs of measurement signals may, of course, be different from each other. Thus, a reconstruction function $f_{12}(S_{1,i}(x), S_{2,i}(x))$ may be different from a reconstruction function $f_{13}(S_{1,i}(x), S_{3,i}(x))$. However, for better legibility the indices of f are dropped above and in the following.

[0109] Optionally, the machine-learning module 34 may try to determine the at least one correlation quantity for groups of measurement signals, such that the at least one correlation quantity is indicative of a correlation be-

tween different groups of input signals.

[0110] For example, the machine-learning module 34 may try to determine a reconstruction function $f(S_{1,i}(x), S_{2,i}(x); S_{3,i}(x), S_{4,i}(x))$ describing a dependence of S_1 and S_2 on S_3 and S_4 .

[0111] Optionally, the measurement signals may be transformed to a latent space by means of the machine-learning module in order to determine the at least one correlation quantity (step S5).

[0112] In other words, the machine-learning module 34 may be configured to extract the most relevant information from the measurement signals, and to determine the at least one correlation quantity based on the information extracted.

[0113] It has turned out that perturbations in any of the input signals $s_1(t)$, $s_2(t)$, $s_3(t)$, $s_4(t)$ that only occur sporadically can be identified based on a latent space representation of the associated measurement signals. In other words, the machine-learning module 34 can identify aggressor signals even if the perturbations caused by the aggressor signal only occur sporadically.

[0114] Moreover, it has turned out that outlier samples in the measurement signals can be identified and treated appropriately based on the latent space representation of the measurement signals.

[0115] At least one aggressor signal may be automatically identified based on the at least one correlation quantity (step S6).

[0116] As already stated above, if a reconstruction function f can be found that describes the interdependency of the measurement signals with a sufficient precision, this is a strong indicator for a correlation between the respective measurement signals, and thus between the input signals associated with the measurement signals.

[0117] Alternatively or additionally, the at least one correlation quantity may be displayed to a user by means of a display 44 of the measurement instrument 14, such that the user of the measurement instrument 14 may decide whether one of the input signals is an aggressor signal based on the at least one correlation quantity determined.

[0118] Even if the final conclusion about the aggressor signal is not performed by the machine-learning module 34, the at least one determined correlation quantity is easier to handle for the user than a bulk of data comprising a long-term observation of the input signals. Accordingly, the measurement instrument 14 described above is easier to handle for a user.

[0119] Moreover, the at least one correlation quantity is determined fully automatic, such that the needed time for identifying aggressor signals is significantly reduced.

[0120] Certain embodiments disclosed herein, particularly the respective module(s), utilize circuitry (e.g., one or more circuits) in order to implement standards, protocols, methodologies or technologies disclosed herein, operably couple two or more components, generate information, process information, analyze information,

generate signals, encode/decode signals, convert signals, transmit and/or receive signals, control other devices, etc. Circuitry of any type can be used.

[0121] In an embodiment, circuitry includes, among other things, one or more computing devices such as a processor (e.g., a microprocessor), a central processing unit (CPU), a digital signal processor (DSP), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a system on a chip (SoC), or the like, or any combinations thereof, and can include discrete digital or analog circuit elements or electronics, or combinations thereof. In an embodiment, circuitry includes hardware circuit implementations (e.g., implementations in analog circuitry, implementations in digital circuitry, and the like, and combinations thereof).

[0122] In an embodiment, circuitry includes combinations of circuits and computer program products having software or firmware instructions stored on one or more computer readable memories that work together to cause a device to perform one or more protocols, methodologies or technologies described herein. In an embodiment, circuitry includes circuits, such as, for example, microprocessors or portions of microprocessor, that require software, firmware, and the like for operation. In an embodiment, circuitry includes one or more processors or portions thereof and accompanying software, firmware, hardware, and the like.

[0123] The present application may reference quantities and numbers. Unless specifically stated, such quantities and numbers are not to be considered restrictive, but exemplary of the possible quantities or numbers associated with the present application. Also in this regard, the present application may use the term "plurality" to reference a quantity or number. In this regard, the term "plurality" is meant to be any number that is more than one, for example, two, three, four, five, etc. The terms "about", "approximately", "near" etc., mean plus or minus 5% of the stated value.

Claims

1. A measurement instrument for testing a device under test (12), wherein the device under test (12) has at least two test points (20, 24), wherein the measurement instrument (14) comprises a first measurement channel (30), a second measurement channel (32), and a machine-learning module (34), wherein the first measurement channel (30) is configured to process a first input signal associated with one of the at least two test points (20, 24), thereby generating a first measurement signal, wherein the second measurement channel (32) is configured to process a second input signal associated with another one of the at least two test points (20, 24), thereby generating a second measurement signal,

wherein the machine-learning module (34) is configured to determine at least one correlation quantity based on the first measurement signal and based on the second measurement signal, and wherein the at least one correlation quantity is indicative of a correlation between the first measurement signal and the second measurement signal.

2. The measurement instrument of claim 1, wherein the machine-learning module (34) comprises an artificial neural network.
3. The measurement instrument according to claim 2, wherein the artificial neural network comprises an autoencoder.
4. The measurement instrument according to any of the preceding claims, wherein the machine-learning module (34) is configured to try to reconstruct the second measurement signal based on the first measurement signal in order to determine the at least one correlation quantity.
5. The measurement instrument according to claim 4, wherein the at least one correlation quantity comprises a reconstruction function, wherein the reconstruction function describes a dependency of the second measurement signal on the first measurement signal.
6. The measurement instrument according to any of the preceding claims, wherein the first measurement channel (30) is configured to pre-process the first input signal such that the first measurement signal comprises statistical information regarding the first input signal, and/or wherein the second measurement channel (32) is configured to pre-process the second input signal such that the second measurement signal comprises statistical information regarding the second input signal.
7. The measurement instrument according to claim 6, wherein the machine-learning module (34) is configured to determine the at least one correlation quantity based on the statistical information.
8. The measurement instrument according to any of the preceding claims, wherein the measurement instrument (14) is configured to process at least one further input signal, thereby generating at least one further measurement signal, wherein the machine-learning module (34) is configured to determine the at least one correlation quantity based on the at least one further measurement signal, and wherein the at least one correlation quantity is indicative of a correlation between the at least one further measurement signal and at least one of the first measurement signal and the second measurement signal.

9. The measurement instrument according to any of the preceding claims, wherein the machine-learning module (34) is configured to transform the first measurement signal and/or the second measurement signal to a latent space in order to determine the at least one correlation quantity. 5
10. The measurement instrument according to any of the preceding claims, wherein the measurement instrument (14) is established as an oscilloscope, as a signal analyzer, or as a vector network analyzer. 10
11. A measurement system, comprising a device under test (12) and a measurement instrument (14) according to any of the preceding claims, wherein the device under test (12) has at least two test points (20, 24). 15
12. The measurement system of claim 11, wherein the device under test (12) comprises a printed circuit board, wherein the printed circuit board comprises the at least two test points (20, 24). 20
13. A signal processing method for testing a device under test (12), wherein the device under test (12) has at least two test points (20, 24), the signal processing method comprising the following steps: 25
 - receiving a first input signal via a first measurement channel (30) and a second input signal via a second measurement channel (32); 30
 - processing the first input signal by means of the first measurement channel (30), thereby generating a first measurement signal;
 - processing the second input signal by means of the second measurement channel (32), thereby generating a second measurement signal; 35
 - and
 - determining at least one correlation quantity being indicative of a correlation between the first measurement signal and the second measurement signal by means of a machine-learning technique. 40
14. The signal processing method of claim 13, further comprising the following step: 45
 - trying to reconstruct the second measurement signal based on the first measurement signal by means of the machine-learning technique in order to determine the at least one correlation quantity. 50
15. The signal processing method of claim 14, wherein the at least one correlation quantity comprises a reconstruction function, wherein the reconstruction function describes a dependency of the second measurement signal on the first measurement signal. 55

Fig. 1

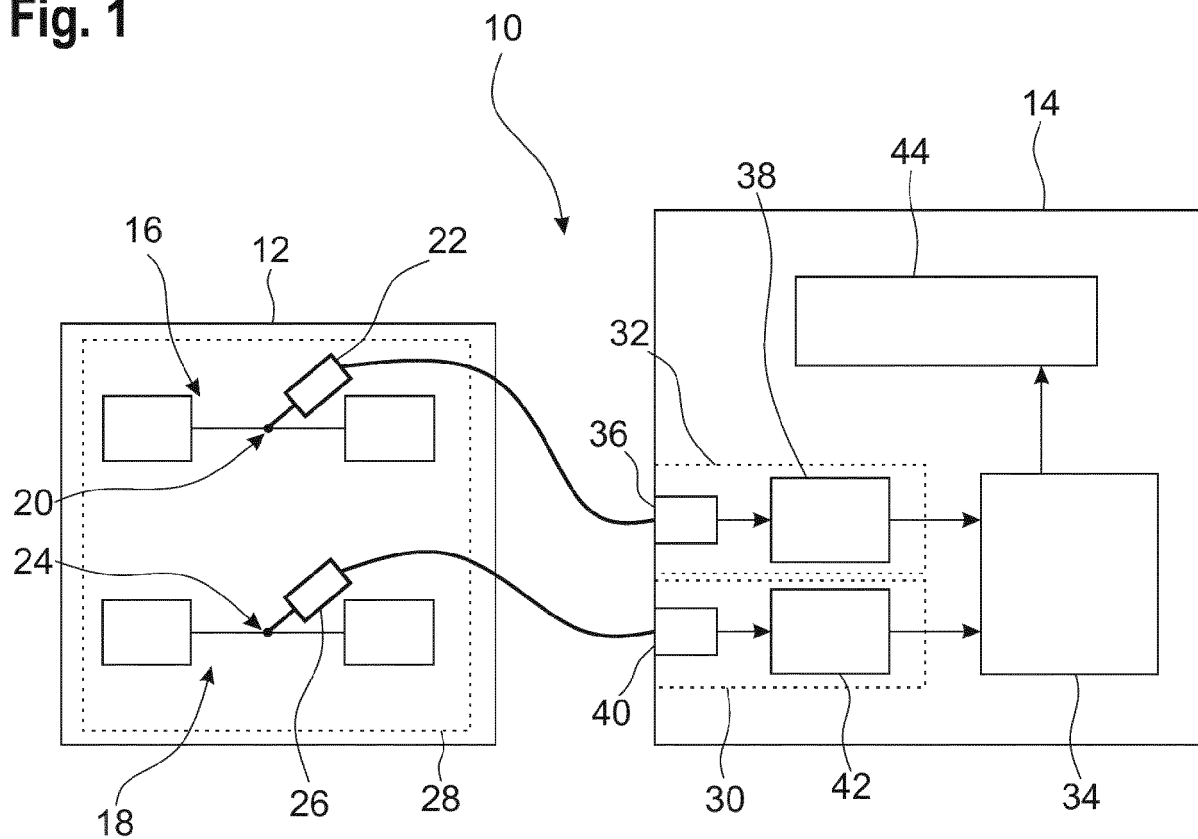


Fig. 2

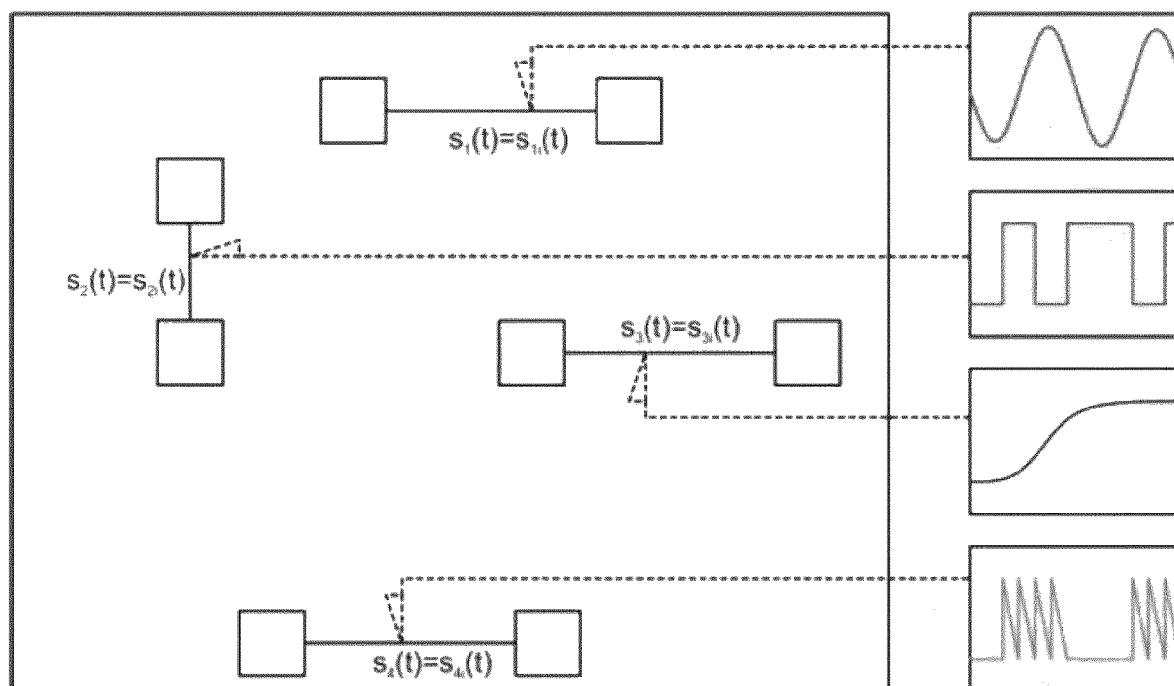


Fig. 3

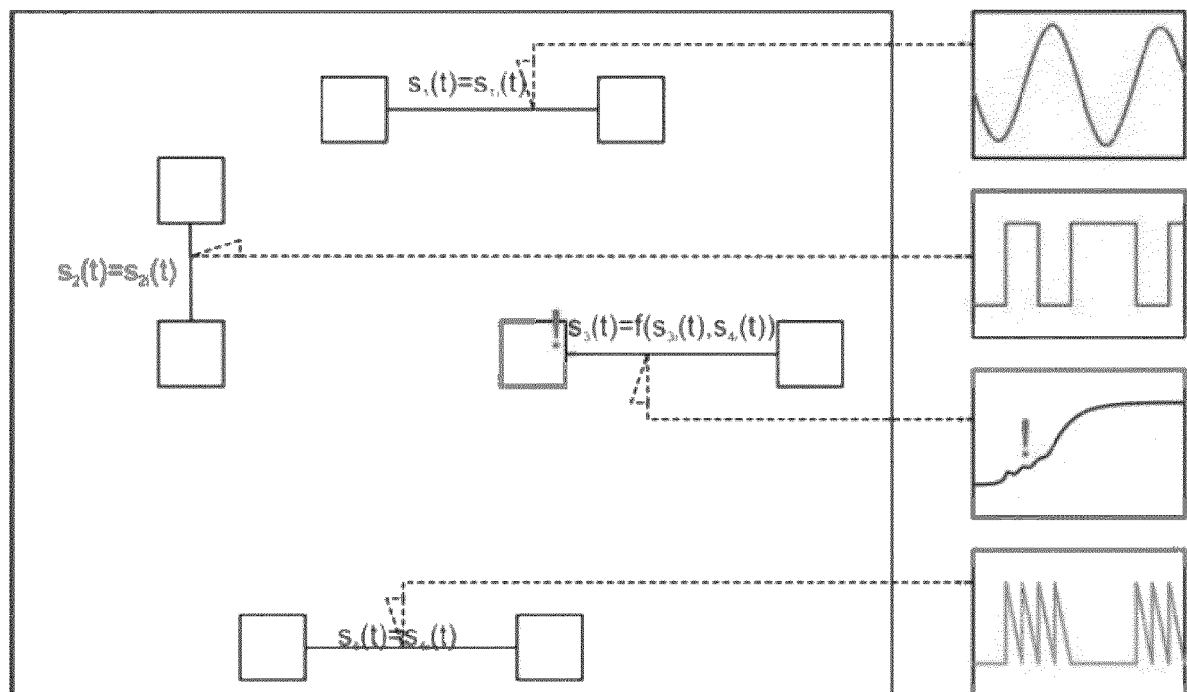


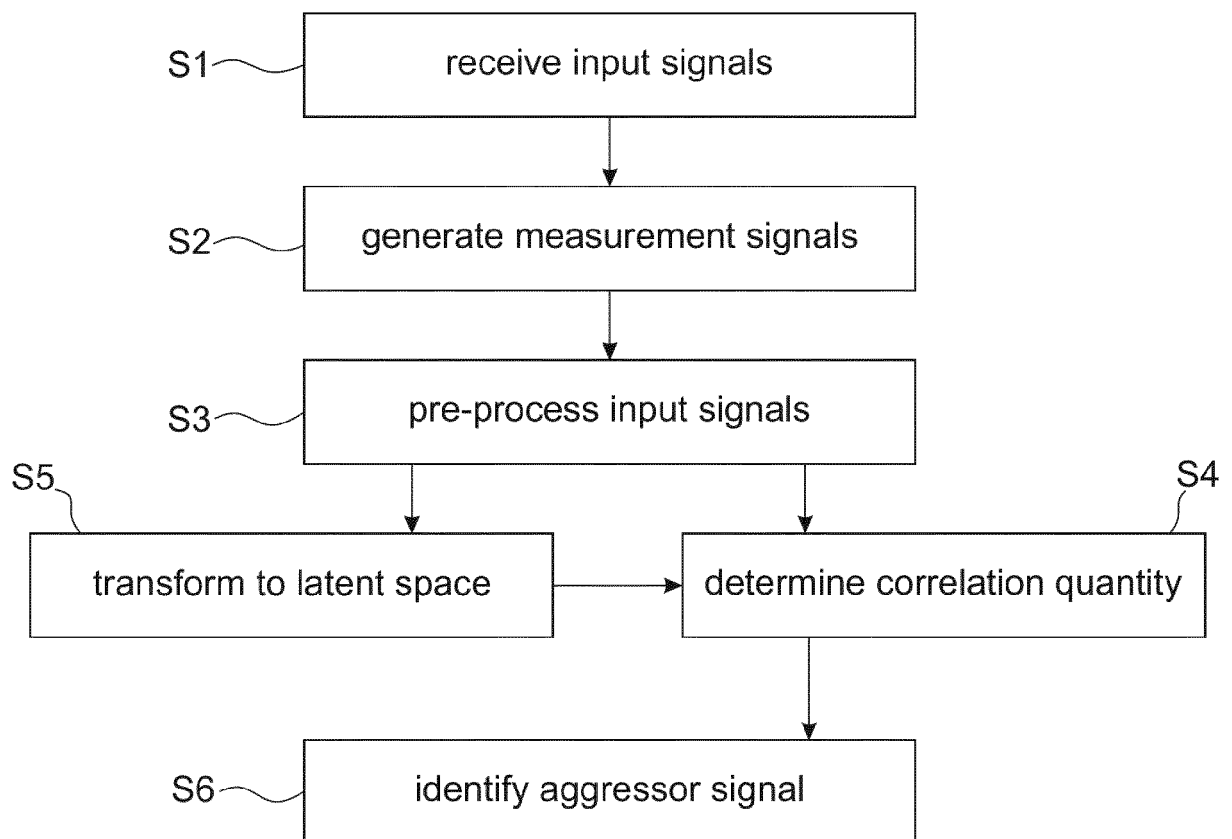
Fig. 4

Fig. 5

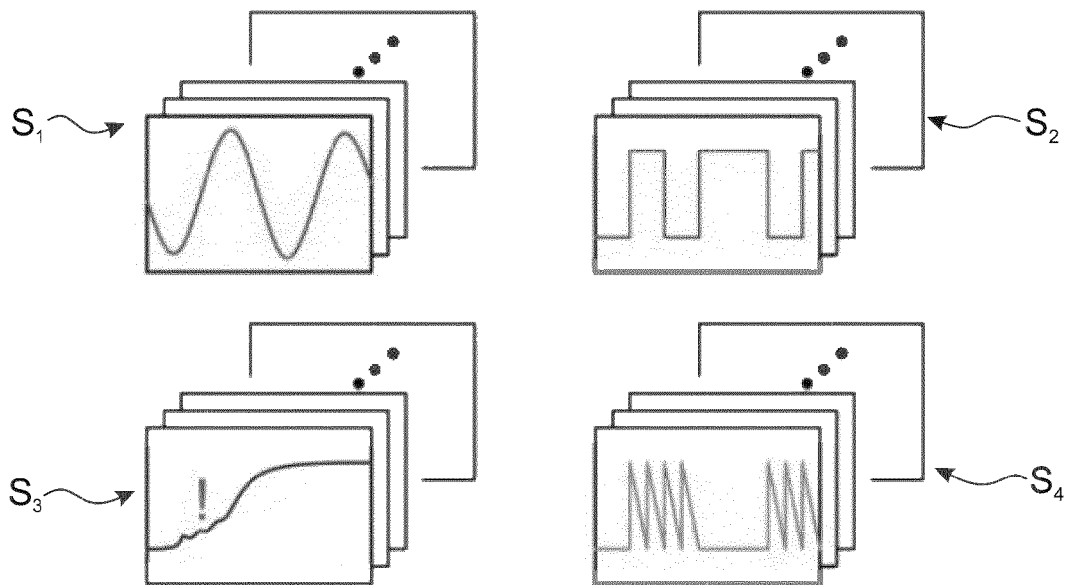
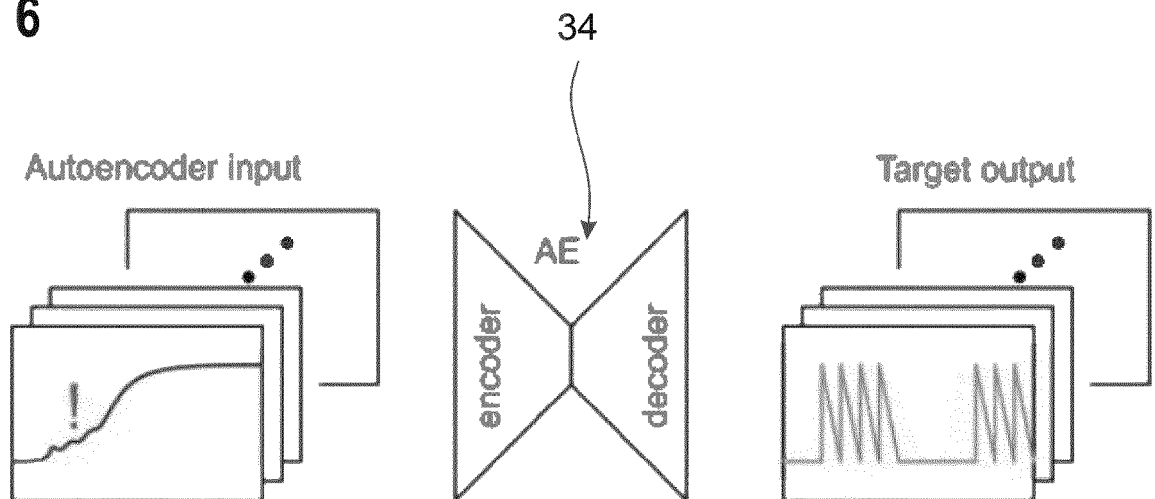


Fig. 6





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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 7 July 2021	Examiner Meggyesi, Zoltán
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		7 July 2021	Meggyesi, Zoltán
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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07-07-2021

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